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Economic feasibility analysis of community solar projects in Hong Kong

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ABSTRACT

Solar initiatives, particularly community solar, have gained increasing traction in urban areas as a means to maximize the advantages of transitioning to clean energy sources. Accordingly, this study aims to assess the economic viability of community solar projects (CSPs) in Hong Kong by evaluating their economic feasibility, analyzing the key factors that influence their economic performance, and exploring the impact of these factors on the performance of CSPs. The findings of this research reveal that, under the current market conditions in Hong Kong, CSPs are deemed unfeasible due to the high upfront installation cost of PV systems. Furthermore, the upfront installation cost and residential payments are identified as the most sensitive variables affecting the overall costs and revenues of such projects. Specifically, a decrease in upfront installation cost or an increase in residential payments can lead to a higher IRR and an improved cumulative cashflow. These empirical findings provide valuable insights into the economic performance of CSPs within the existing market conditions in Hong Kong, as well as their potential variations under different scenarios. Consequently, this study is believed to offer significant guidance in formulating appropriate financial goals and relevant strategies to facilitate the adoption of community solar initiatives, not only in Hong Kong but also in other regions sharing similar local characteristics.

Keywords: community solar projects, economic feasibility, sensitivity analysis, scenario analysis

NONMENCLATURE

Abbreviations	
PV	Solar Photovoltaic
CSP	Community Solar Projects
IRR	Internal Rate of Return
CV(RMSE)	Coefficient of Variance of Root Mean Square Error
PT	Profit tax
CCF	Cumulative Cashflow
FiT	Feed-in Tariff
PAYG	Pay-as-you-go
UIC	Upfront Installation Cost
CI	Cash Inflow
CO	Cash Outflow
Symbols	
n	Year
a_i	Predicted Value
$\hat{a}_i$	Empirical Value
$\bar{a}_i$	Mean Value of All Predicted Values
n	Number of Simulations
t	Year

1. INTRODUCTION

In recent years, the global energy landscape has witnessed a significant shift towards sustainable and renewable sources of energy. Renewable energy technology is therefore under rapid development and is widely applied in various industries worldwide. Among various renewable energy technologies adopted in buildings, solar photovoltaic (PV), which converts solar energy directly into electricity, is extensively gaining traction [1]. In reality, residential rooftop solar and utility-scale solar are the most common practices. Despite the mature and promising potential for PV technology to retrench global reliance on fossil fuels, PV development is still experiencing complex challenges, including land use conflict [2], financial access [3], social resistance [4]. For example, it is often the case that an individual property does not meet the required conditions to install a rooftop solar PV system (e.g., improper orientation, not enough roof space, too much shade, too many upfront costs) [5]. Moreover, traditional

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utility-owned solar predominantly does not create benefits for specific end-users or fully incorporate local preferences of project host communities [6]. Accordingly, community solar project (CSP) has emerged as a viable approach to harnessing solar energy for those who want to overcome the above limitations [7, 8].

There is no widely adopted definition of "community solar" and different organizations or researchers have adopted different definitions. This study referred to the definition from Beck, Chan [6]: Community solar is a solar installation with multiple off-takers (referred to as 'subscribers') who enter into a contractual relationship with the owner or operator of the installation (or an intermediary) to receive some or all of the financial returns from a predefined share of the installation's output. These initiatives enable multiple participants, often residents or businesses within a specific community, to collectively own or subscribe to a shared solar energy system, thereby reaping the benefits of solar power generation. While community solar projects hold immense potential, their economic feasibility remains a critical aspect that must be thoroughly investigated. These initiatives often require substantial upfront investments, entail complex financial arrangements, and demand careful assessment of various economic factors.

Therefore, financial challenges have broadly been identified as impediments to the adoption of CSPs due to significant upfront investments, previous studies explored the financial feasibility of CSPs under different contexts based on various assumptions on financial parameters (e.g., discount rate, electricity rate, total capital costs of solar PV systems). For example, Awad and Gül [9] analyzed the feasibility of community solar based on cost minimization metric by utilizing the Monte Carlo Simulation technique. Oh and Son [10] explored the effects of various service methods for community solar on the profit and fairness to maximize profit and achieve fairness through Lagrangian relaxation and dual ascent method. These relevant studies provide insights into the economic analysis of CSPs and relevant research methods. Assumptions regarding financial parameters in previous studies are often set in stone, predicated on the local context. However, the inherent variability and uncertainty of local contexts can compromise the accuracy and predictability of economic analysis results pertaining to CSPs.

Hence, this research aims to evaluate the basic economic feasibility of CSPs, scrutinize the key factors that impact economic performance, and examine the influence of these factors on the economic performance of CSPs. To this end, the following research questions will be addressed: (1) What is the economic feasibility of CSPs in Hong Kong?; (2) Which cost and revenue components are instrumental in determining the financial performance?; and (3) To what extent do diverse components affect the economic performance of CSPs? A financial model based on life cycle cost analysis will be proposed to evaluate the economic performance across various financial metrics. Sensitivity analysis will be employed to investigate critical factors that affect the costs and revenues of CSPs. Subsequently, scenario analysis will be conducted to explore the impact of significant cost and revenue components on the economic performance of CSPs, as well as the overall appeal of CSPs under different conditions. It is anticipated that the findings of this study will contribute towards a comprehensive understanding of the economic viability and attractiveness of CSPs in Hong Kong, and facilitate the development of suitable CSPs that consider the benefits of developers and subscribers, thereby promoting distributed solar generation through community solar adoption.

2. MATERIAL AND METHODS

Currently, the Feed-in tariff (FiT) is considered an effective and efficient tool to promote solar PV projects by providing incentives for the private sector to invest in renewable energy systems. However, the FiT in Hong Kong will be gradually phased out and expired in 2033, even though the current rate may not guarantee sufficient coverage of the investment cost of solar panels in Hong Kong [11]. As such, proposing a more sustainable electricity trading mechanism is critically important to Hong Kong's renewable energy policy reform.

Towards this end, this study proposes a business model of CSP as illustrated in Fig. 1, where PV systems are invested and installed by the developer, and the PV-generated electricity can be directly sold from the developer to different types of customers (e.g., residential, non-residential, and large) by Pay-as-you-go (PAYG) subscription method. PAYG is adopted in this study because it is expected to increase the participation rate by enhancing financial availability and flexibility [12-14], where customers are charged based on their usage of the service or product. Additionally, customers (i.e., subscribers) have the option to purchase electricity from utility companies to meet any unmet electricity demands. Notably, in the proposed CSP, the developer assumes the role of project leader and assumes responsibility for the entire lifecycle of the CSP, including installation, operation, and maintenance. This role can be undertaken by a single entity or a variety of entities, such as utility companies, private companies, or non-profit organizations.

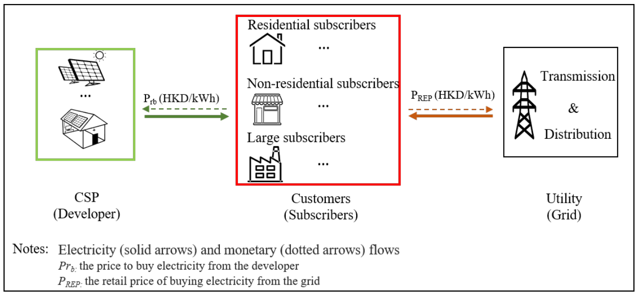

Fig. 1. Schematic representation of proposed community solar project in Hong Kong

To understand how economic performance of a CSP in Hong Kong is influenced by various key cost and revenue components, this study will be conducted in three steps. The first step involves calculating the economic performance of the CSP based on assumed community solar rates and subscription rates. The assumed community solar rate is set equal to the retail electricity price. For residential, non-residential, and large subscribers, the subscription rates are assumed to be 50%, 25%, and 25%, respectively, aligning with the customer segments observed in the U.S. market in 2021 [15]. Moving on to the second step, the study aims to identify the key cost and revenue components that significantly impact the economic performance of CSPs through a sensitivity analysis. Finally, in the third step, the study will propose various scenarios based on the findings from the second step. By comparing the economic analyses of these different scenarios, the study seeks to understand and quantify the specific impact of key cost and revenue components on the economic performance of CSPs. This will allow for a comprehensive evaluation of the financial implications associated with implementing CSPs in Hong Kong.

3. THEORY/CALCULATION

To evaluate the economic performance of CSPs, a financial model is proposed based on life cycle cost analysis. The specifications of the financial model are shown in Table 1. The result of the annual PV-electricity generation estimated in this study is validated by six regional annual PV system electricity generation data provided from the Hong Kong Solar Irradiation Map [16], based on the coefficient of variance of root mean square error (CV(RMSE)) shown in Eq. (1). Accordingly, the value of CV(RMSE) is calculated as 6.7%, which is less than 25% and indicates the calculation of PV system electricity generation in this study is of high accuracy. Profit tax (PT) in this table refers to the profit tax of year t (HKD) and can be calculated by Eq. (2). According to the Land Revenue Department of Hong Kong [17], tax is not exempted since the installers are usually business sectors.

$$CV(RMSE) = \frac{1}{\bar{a}_i}\sqrt{\sum_{i=1}^{n}\frac{(a_i-\hat{a}_i)^2}{n}} \quad (1)$$

$$PT_t = \begin{cases} CI_t * 8.25\%, & CI_t \leq 2{,}000{,}000 \\ CI_t * 16.5\% - 165{,}000, & CI_t > 2{,}000{,}000 \end{cases} \quad (2)$$

Table 1. Specifications of financial model and data used in this study

Part	Category	Sub-category	Data
Project cash outflow	System capital cost	Upfront installation cost (UIC)	3.72 US$/W
		Upfront administrative cost	3.6% of UIC
	Financial cost	Debt	50% of UIC
		Interest payment	IPMT function with 5% interest rate
		Debt principal payment	PPMT function with 5% interest rate
	Operation cost	Operation and maintenance cost	1% of UIC
		System removal cost	5% of UIC
		Insurance cost	0.25% of UIC
		Profit tax	Refer to Eq. (1)
Project cash inflow	Subscriber payment	Total subscription of subscriber	Residential subscribers: 500 kW; Non-residential subscribers: 250 kW; Large subscribers:250 kW
		Community solar rate	Retail electricity price
	Incentive payment	Innovation and technology fund	90% of CO or 639920 US$, whichever is less
		Expenditure on environmenta l protection facilities	360,000 US$
	System production benefit	Unsubscribed energy payments	0.088 *Amount of unsubscribed energy (US$)

The results of the financial model can be presented in various financial indices, as shown below:

- Cumulative cashflow (CCF)

CCF is the accumulated cash inflows and outflows of a project over the years from the very beginning of the project, which helps to determine the worth of the project at the current time. Eq. (3) can be used to calculate CCF.

$$CCF = \sum_{t=1}^{T} CI_t - CO_t \quad (3)$$

- Internal rate of return (IRR)

IRR evaluates the expected return of investment (%), expressed as a percentage, to produce for the investors above the hurdle rate. The calculation of IRR is the discount rate needed for net present value (NPV) equals to zero, as shown in Eq. (4).

$$NPV(IRR) = \sum_{t=1}^{T} \frac{CI_t - CO_t}{(1+IRR)^t} = 0 \quad (4)$$

4. RESULTS AND DISCUSSION

Table 2 presents the analysis results regarding the economic performance of a CSP in Hong Kong under existing market conditions. The results indicate an unfavorable economic feasibility of the CSP, as evidenced by a negative NPV and IRR. According to the research by Yan, Yang [18], solar projects are considered unprofitable when the IRR falls below 8.5%, while an IRR exceeding 16% suggests high profitability. When comparing the findings with those in other regions/locations, it is apparent that the high upfront installation costs of PV systems in Hong Kong greatly contribute to the poor economic feasibility of CSPs. As a result, in order to achieve attractive financial outcomes, community solar rates would need to exceed the retail electricity prices offered by utility companies. However, it is worth noting that such higher community solar rates may diminish subscribers' willingness to participate in CSPs. Therefore, based on the current market conditions, it is imperative to address the issue of high upfront installation costs in order to improve the economic viability of CSP projects in Hong Kong. Additionally, careful consideration should be given to strike a balance between setting community solar rates that can ensure financial feasibility and maintaining a sufficiently attractive offering for potential subscribers.

Table 2. Economic performance of a CSP in Hong Kong

Indicator	Total	Per unit
25-year costs	-7,502,662.82 US$	-7.50 US$
25-year revenues	6,357,138.31 US$	6.36 US$
25-year net benefits	-1,145,524.50 US$	-1.15 US$
25-year NPV	-1,019,708.48 US$	-1.02 US$
IRR	-2%	

Based on the results above, sensitivity analysis has been conducted to evaluate the influence of various factors on the project cost and revenues. In this analysis, factors are evaluated by considering scenarios with a 5%

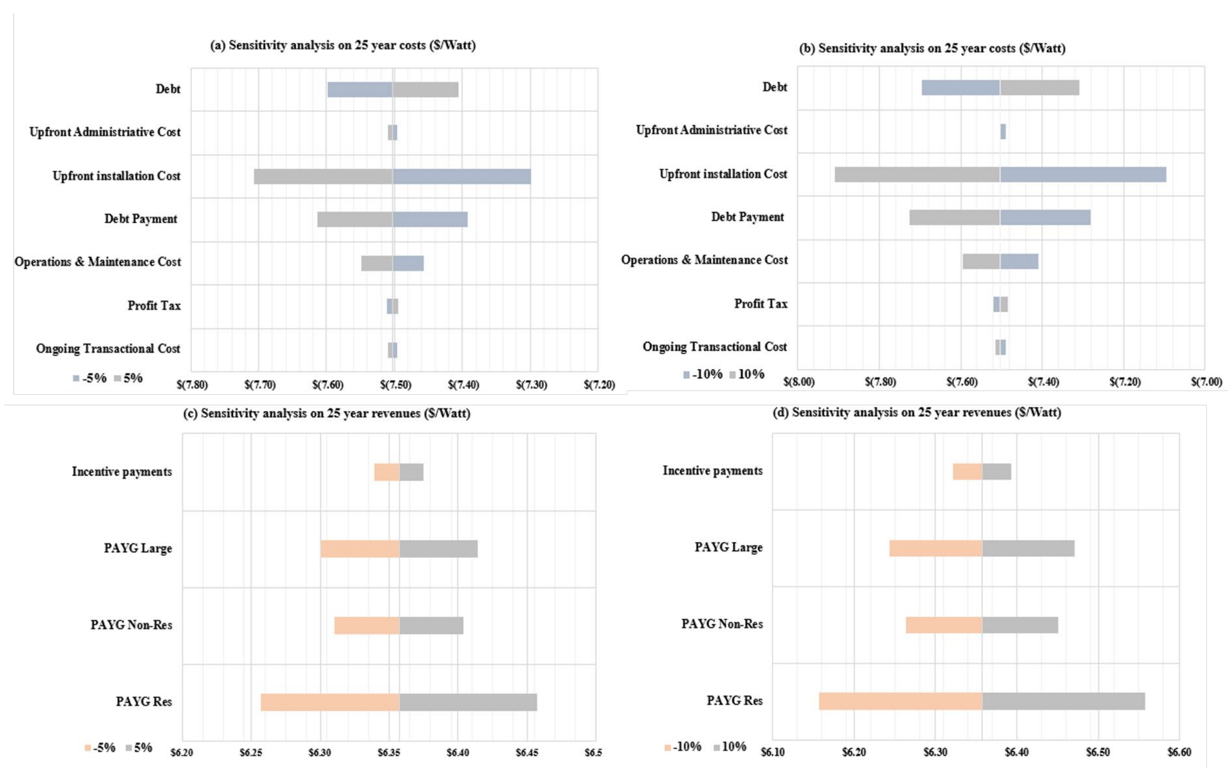

Fig. 2. Results of sensitivity ananlysis

and 10% increase and decrease (-/+ 5% and -/+ 10%). The outcomes of this sensitivity analysis are depicted in Fig. 2, where the length of the bars symbolizes the degree of sensitivity, with longer bars indicating greater sensitivity. It can be observed that the upfront installation cost exhibits the highest degree of influence or sensitivity on project costs. This implies that variations in the upfront installation cost have a substantial impact on the overall cost of the CSP project. Conversely, when it comes to revenue, residential payments emerge as the most sensitive variable. This suggests that changes in residential payments significantly affect the revenue generation potential of the CSP system. These findings underscore the importance of carefully considering and managing the upfront installation cost and residential payment structure in order to optimize the economic performance of CSP projects in Hong Kong. By doing so, stakeholders can ensure that project costs are effectively controlled and that revenue streams are maximized, thereby enhancing the financial viability and sustainability of CSP systems in the region.

To further investigate the impact of key cost and revenue components on the economic performance of a CSP project, two scenarios have been proposed based on the results of the sensitivity analysis. The first scenario focuses on exploring the effects of changes in the upfront installation cost on both the IRR and CCF. In this scenario, variations in the upfront installation cost (-/+ 10%, -/+ 20%, and -/+ 30%) have been considered, and the corresponding results are illustrated in Fig. 3 (a) and (c). The second scenario focuses on investigating the impact of changes in the total payment of residential subscribers on both IRR and CCF. In this scenario, variations in residential payments (-/+ 10%, -/+ 20%, and -/+ 30%) have been considered, and the respective outcomes are illustrated in Fig. 3 (b) and (d).

Analysis of the results reveals that the IRR increases as the upfront installation cost decreases (see Fig. 3 (a)). For instance, when the upfront installation cost decreases by 30%, the IRR reaches 4.2%, which, however, is still lower than the target rate of 8.5%. It is worth noting that the solar PV industry has achieved a level of maturity globally after several decades of development, whereas the solar PV market in Hong Kong is still in its early stages of growth [19]. As the solar market in Hong Kong continues to mature, it is expected that the upfront installation cost of PV systems will gradually decrease, aligning with the declining trend observed worldwide. This, in turn, would help to lower the upfront installation cost and meet the desired financial objectives. In addition, the analysis has revealed that a rise in residential payments is associated with a beneficial effect on IRR, as demonstrated by the findings presented in Fig. 3 (b). This outcome aligns with expectations, as higher residential payments have the potential to augment the project's cash inflow, leading to

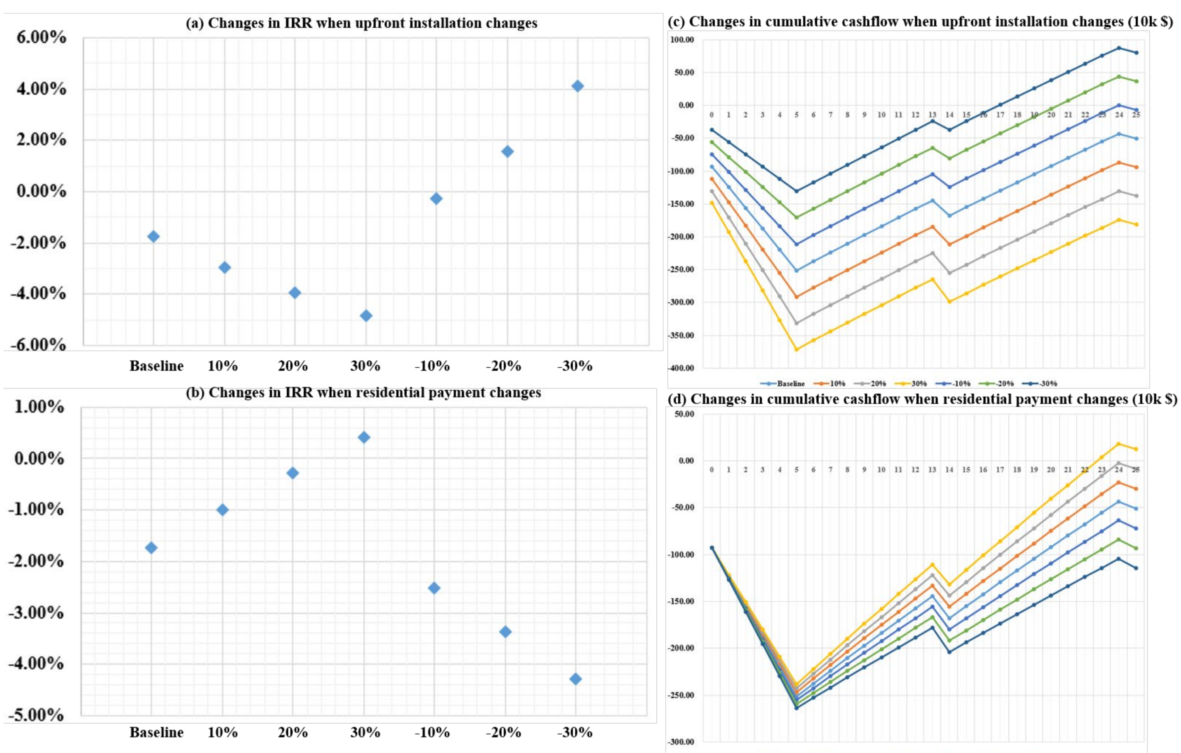

Fig. 3. Results of scenario analysis

an overall increase in net cashflow and improved economic performance in terms of IRR. Therefore, it is crucial to consider strategies that enhance residential payments in order to optimize the financial viability of CSPs in Hong Kong.

In terms of CCF, it can be concluded from Fig. 3 (c) that a higher upfront installation cost leads to a poorer performance on cumulative cashflow. Conversely, to achieve a favorable economic performance in cumulative cashflow, a lower upfront installation cost is required. This finding underscores the importance of minimizing the upfront installation cost in order to optimize the economic viability of community solar projects. Moreover, it has been observed in Fig. 3 (d) that higher residential payments contribute to improved economic performance in terms of cumulative cashflow. This result aligns with expectations, as higher residential payments translate into increased revenue and, consequently, enhance the overall financial prospects of community solar projects. Therefore, it is recommended to facilitate and promote residential payments by attracting a larger number of potential residential subscribers to a CSP or raising community solar rate for residential subscribers in order to improve its economic performance and ensure sustainability. By considering these findings from scenario two, stakeholders can design and implement effective measures to optimize the financial performance of community solar projects, ultimately leading to their long-term success and contribution to the renewable energy sector.

5. CONSLUSIONS

In response to climate impacts, many cities formulated low-carbon initiatives that involved a wide spectrum of new energy technologies. Solar initiatives in cities, particularly community solar, are increasingly utilized to maximize the benefits of energy transitions. This study understands economic feasibility of a CSP in Hong Kong by evaluating the basic economic feasibility, analyzing the key factors influencing economic performance, and exploring the impact of such factors on economic performance of CSPs. The results indicate CSPs are infeasible in current Hong Kong's market conditions due to the high upfront installation cost of PV systems. In addition, upfront installation cost and residential payments are the most sensitive variables on the cost and revenue. Moreover, the scenario analysis results indicate that a decrease in upfront installation cost or an increase in residential payments can lead to a higher IRR and an improved cumulative cashflow. The findings provide insights into the economic performance of CSPs in the current market and its changes under different scenarios in Hong Kong, which is believed to provide significant references in designing appropriate financial goals and relevant strategies to promote community solar adoption.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

REFERENCE

[1] Jayaweera N, Jayasinghe CL, Weerasinghe SN. Local factors affecting the spatial diffusion of residential photovoltaic adoption in Sri Lanka. Energy Policy. 2018;119:59-67.

[2] Adeh EH, Good SP, Calaf M, Higgins CW. Solar PV power potential is greatest over croplands. Scientific reports. 2019;9:11442.

[3] Swain MMC. Managing stakeholder conflicts over energy infrastructure: case studies from New England's energy transition: Massachusetts Institute of Technology; 2019.

[4] Batel S, Devine-Wright P, Tangeland T. Social acceptance of low carbon energy and associated infrastructures: A critical discussion. Energy Policy. 2013;58:1-5.

[5] Lo K, Mah DN-Y, Wang G, Leung MKH, Lo AY, Hills P. Barriers to adopting solar photovoltaic systems in Hong Kong. Energy & Environment. 2018;29:649-63.

[6] Beck AL, Chan G, Rai V. Scaling community solar in Texas: Barries, strategies, and roadmap. 2020.

[7] Burch J, Woods J, Kozubal E, Boranian A. Zero energy communities with central solar plants using liquid desiccants and local storage. Energy Procedia. 2012;30:55-64.

[8] Noll D, Dawes C, Rai V. Solar community organizations and active peer effects in the adoption of residential PV. Energy policy. 2014;67:330-43.

[9] Awad H, Gül M. Optimisation of community shared solar application in energy efficient communities. Sustainable Cities and Society. 2018;43:221-37.

[10] Oh E, Son S-Y. Community solar photovoltaic service strategy for commercial buildings considering profit balancing and fairness. Energy and Buildings. 2020;229:110513.
[11] Dato P, Durmaz T, Pommeret A. Feed-in tariff policy in Hong Kong: Is it efficient? City and Environment Interactions. 2021;10:100056.
[12] Chan G, Evans I, Grimley M, Ihde B, Mazumder P. Design choices and equity implications of community shared solar. The Electricity Journal. 2017;30:37-41.
[13] Chan G, Grimley M, Arnold E, Evans I, Herbers J, Hoffman M, et al. Community shared solar in Minnesota: Learning from the first 300 megawatts. 2018.
[14] Chang V, Goldenberg C, Hoskins J, Lassiter S, Li Z, Nakatani E, et al. Solar gardens in the Garden State: community solar recommendations for New Jersey. 2017.
[15] Galen B, Naïm D, Eric OS, Sydney F. Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States. 2022.
[16] EMSD EaMSD. Hong Kong Solar Irradiation Map. 2022.
[17] IRD IRDoHK. Profits tax of buisnesses. 2023.
[18] Yan J, Yang Y, Elia Campana P, He J. City-level analysis of subsidy-free solar photovoltaic electricity price, profits and grid parity in China. Nature Energy. 2019;4:709-17.
[19] Mah DN-y, Wang G, Lo K, Leung MKH, Hills P, Lo AY. Barriers and policy enablers for solar photovoltaics (PV) in cities: Perspectives of potential adopters in Hong Kong. Renewable and Sustainable Energy Reviews. 2018;92:921-36.